FONDAMENTI DI FISICA MEDICA

PARTE 2: METODI D'IMMAGINE IN MEDICINA NUCLEARE (1CFU)

LECTURE 3 – POSITRON EMISSION TOMOGRAPHY (PET)

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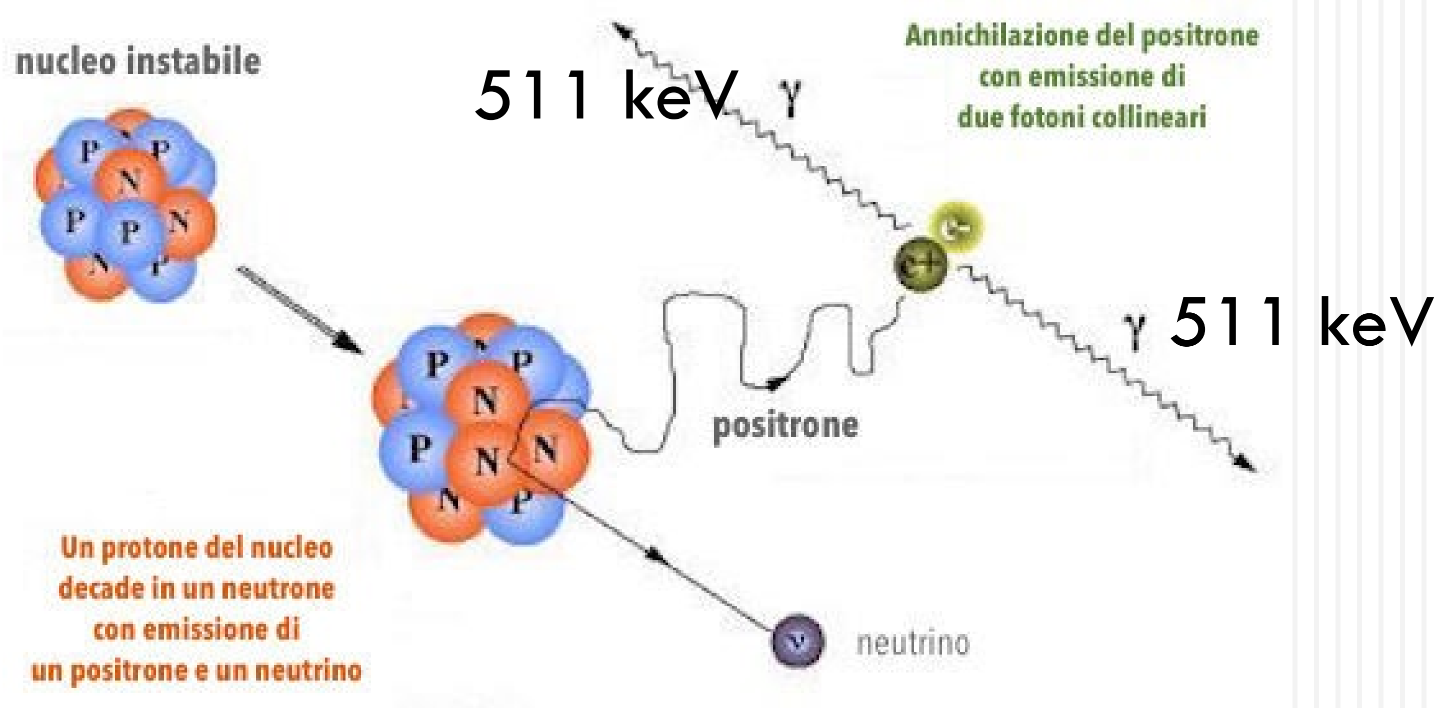
PET

- Introduction to medical physics
  De Ponti & Bertocchi, Chapter 6,
  Nuclear Medicine Imaging
  Stephen Keevil, *et al*. editors
- Comprehensive Biomedical Physics
  T.K. Lewellen, Vol.1, Chapter 6,
  A. Brahme & T.F. Budinger editors

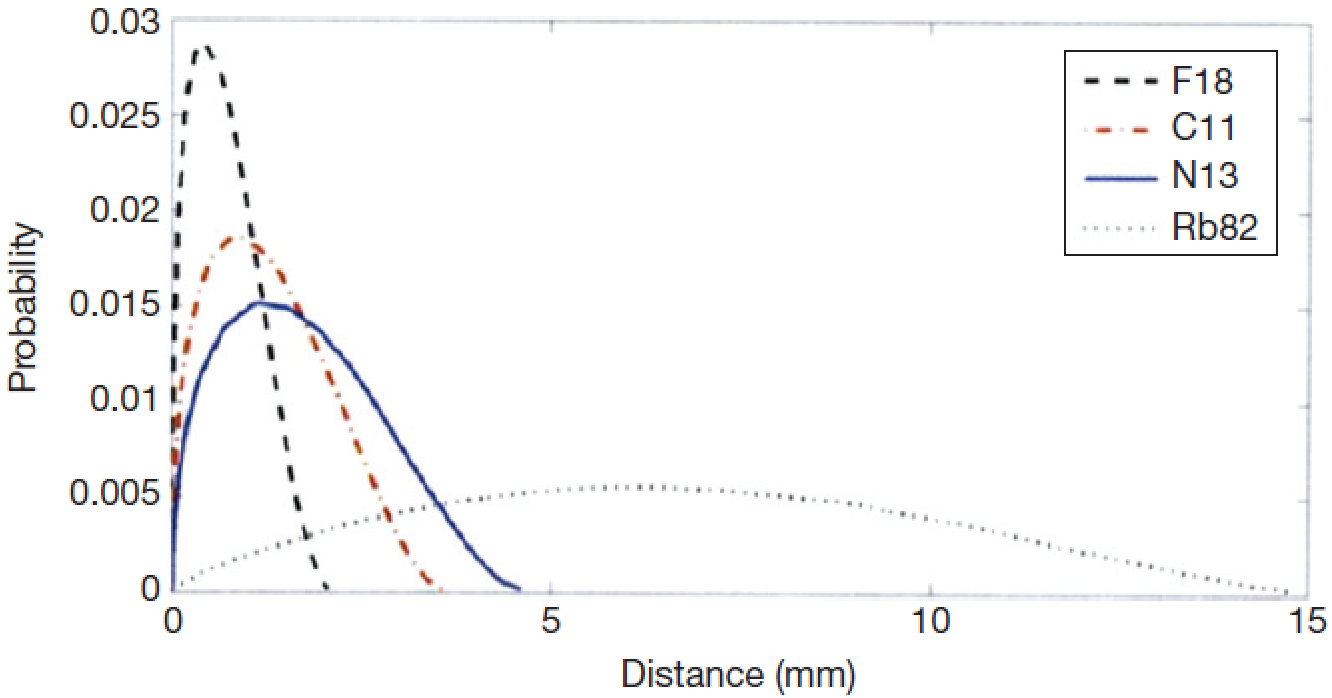
Positron Annihilation

- Following Beta+ decay, the positron quickly loses its kinetic energy and then annihilates with an electron, emitting two 511 keV photons, back-to-back approximately along the same line



Range of the positron

- In PET we detect the two annihilation gamma rays – defining a line in space (line of response – LOR)
- The degree of separation between the LOR and the actual point of decay (range) can be large and depends on the energy of the positron (i.e. on the radionuclide)

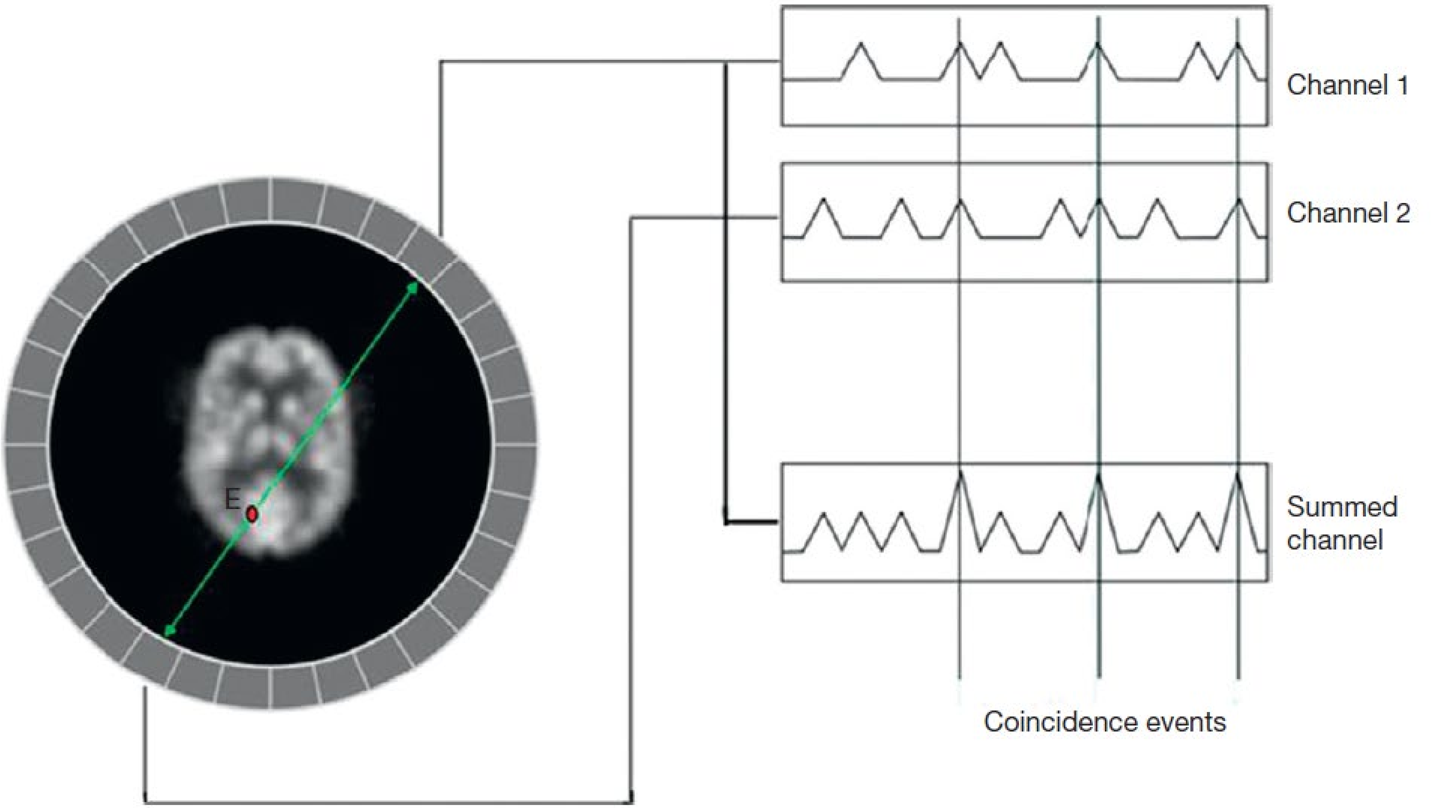


Non-collinearity

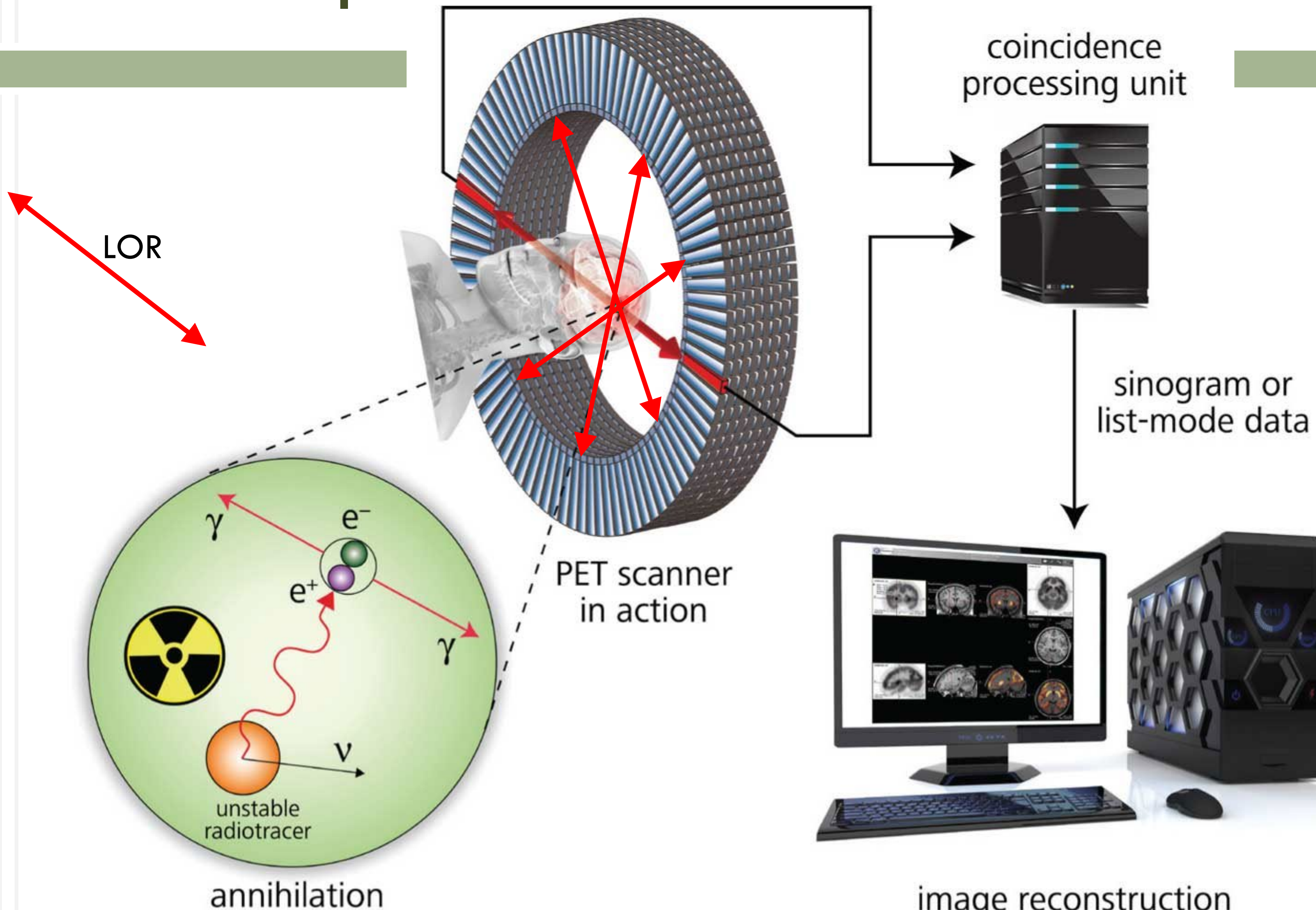
- Actually, the annihilation photons are not necessarily emitted 180° apart, due to the momentum of the positron just before it annihilates with an electron
- The angular spread of the annihilation photons is in the order of $\pm$ 0.25°
- The goal of PET is to make an accurate image of the distribution of the radionuclide in the object being imaged
- Both the positron range and non-collinearity add to decrease the scanner spatial resolution

PET Principle

- PET utilizes the simultaneous (= in coincidence) detection of the two 511 keV photons
- Coincidence allows to avoid the use of collimators



PET Principle



True and False Coincidences

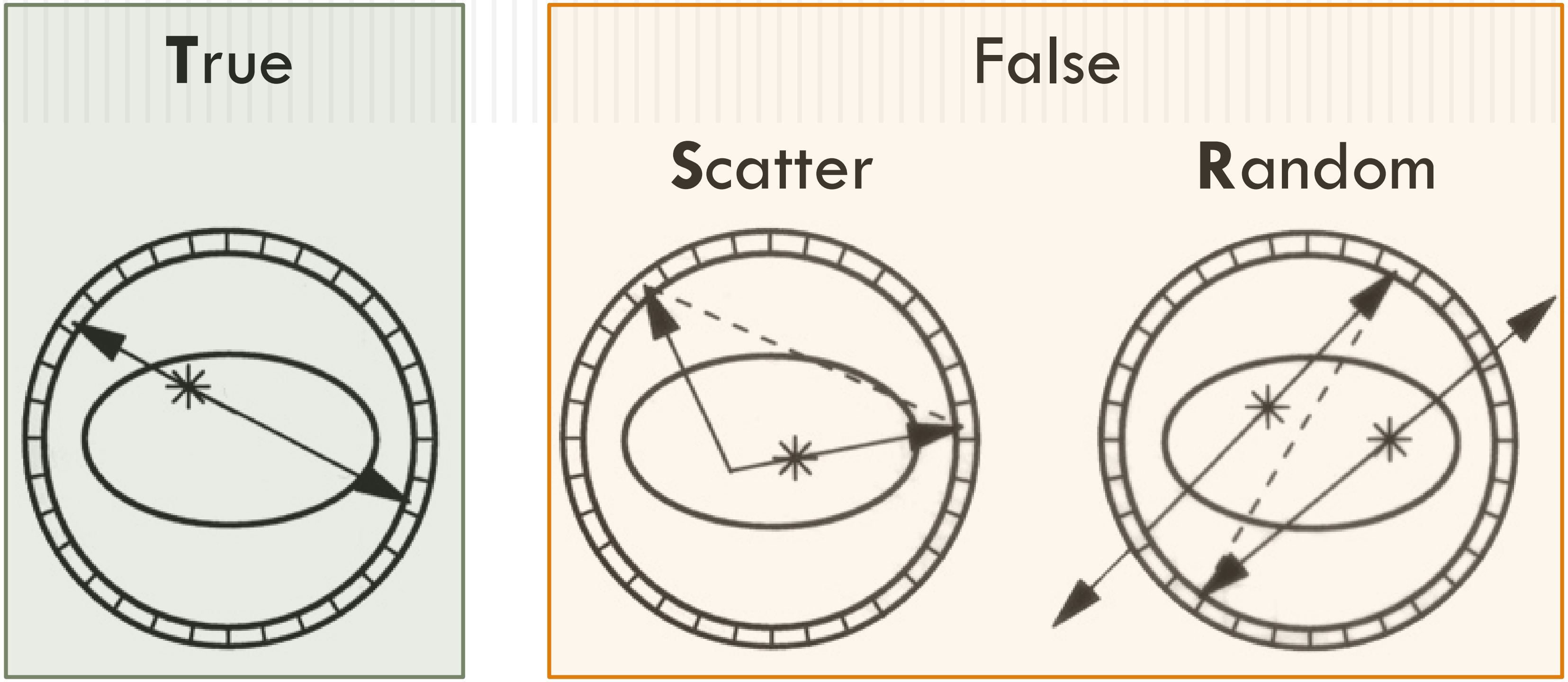
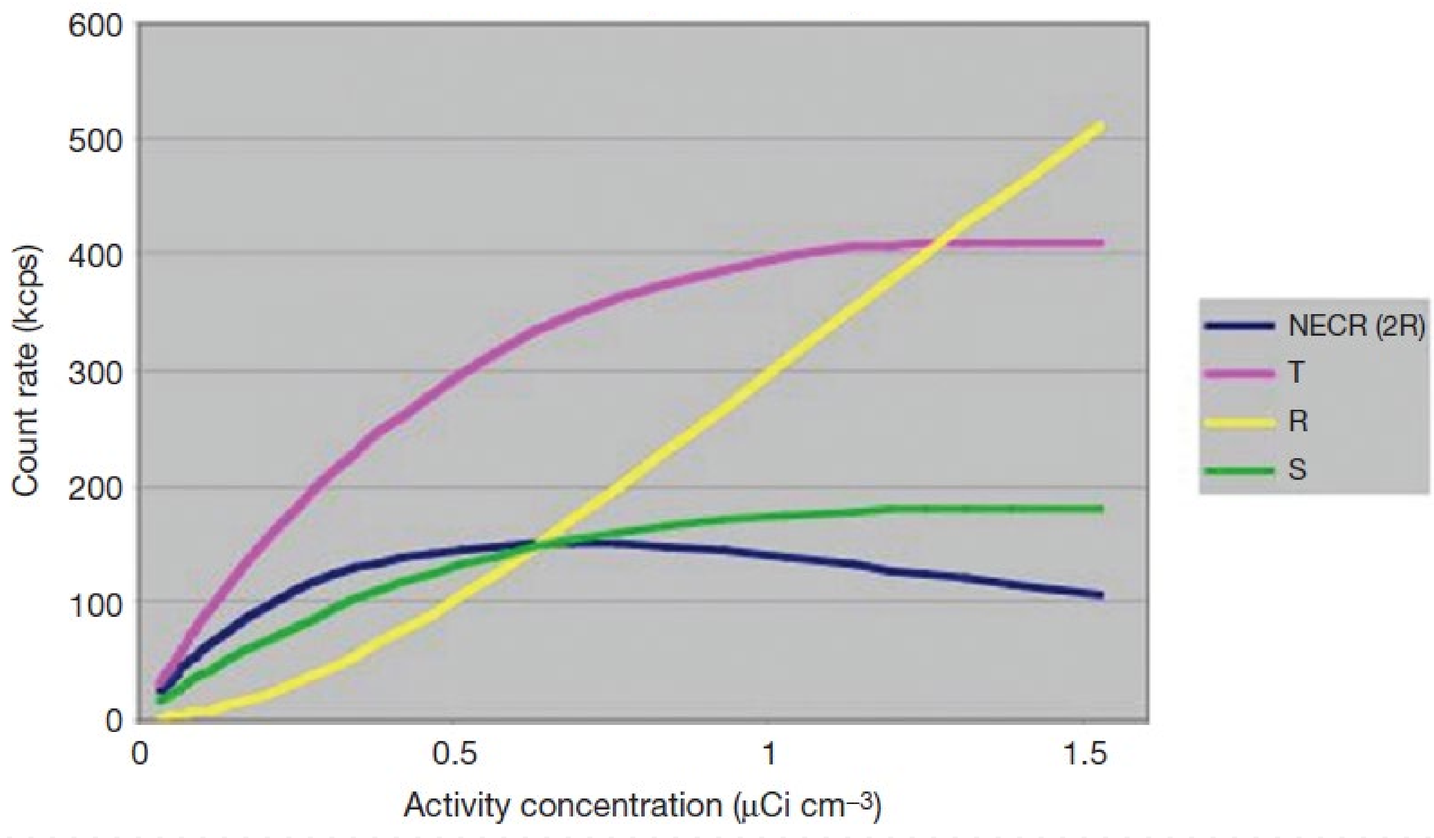


FIGURE 22-15. True coincidence **(left)**, scatter coincidence **(center)**, and random (accidental) coincidence **(right)**. A scatter coincidence is a true coincidence, because it is caused by a single nuclear transformation, but results in a count attributed to the wrong line-of-response *(dashed line)*. The random coincidence is also attributed to the wrong line of response.

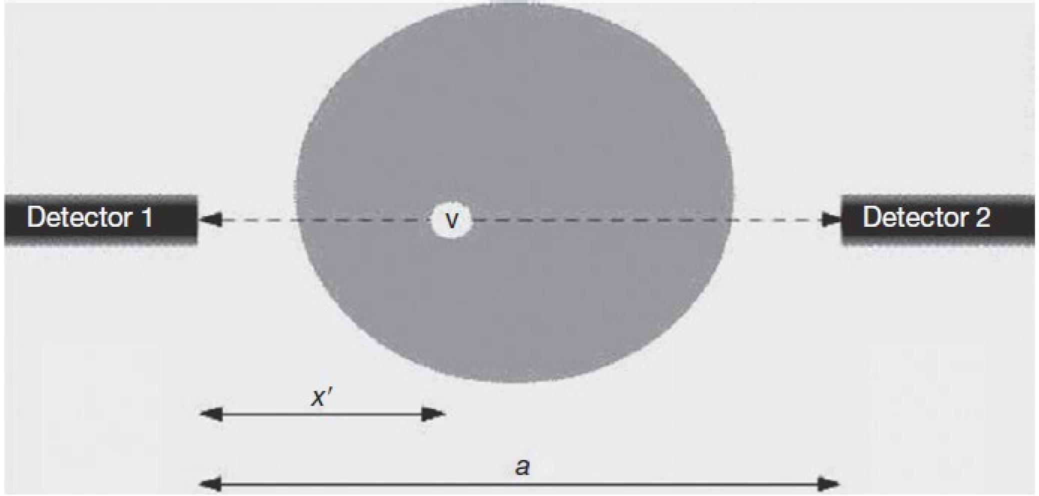
Noise Equivalent Count Rate (NECR)

- $NECR = \frac{T^2}{T+S+K\,R}$ with typically K = 2



Attenuation Correction in PET

- Unlike in SPECT, in PET the correction for attenuation of gamma rays along any LOR is independent of the position of the radionuclides along the LOR



$$P_1 = e^{-\int_0^{x'} \mu(x)\mathrm{d}x}, \quad P_2 = e^{-\int_{x'}^{a} \mu(x)\mathrm{d}x}$$

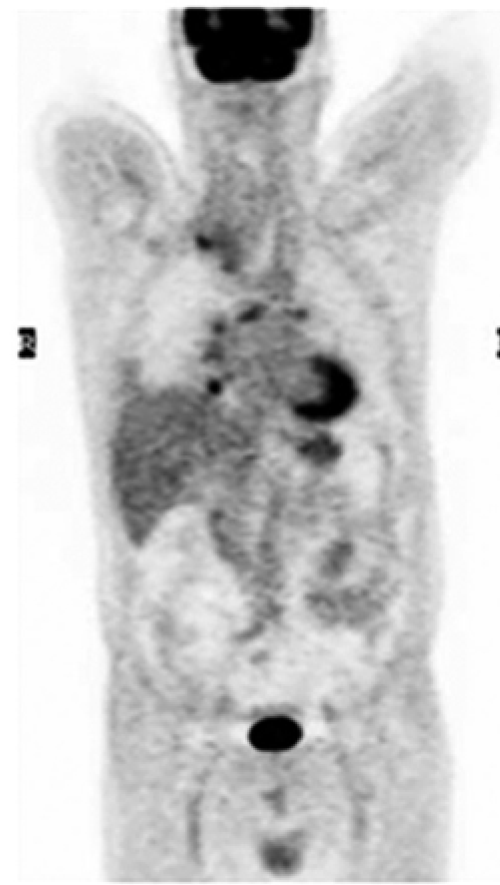
$$P_d = P_1 P_2 = e^{-\int_0^{a} \mu(x)\mathrm{d}x}.$$

PET/CT for attenuation correction

- Uncorrected PET + CT = Corrected PET

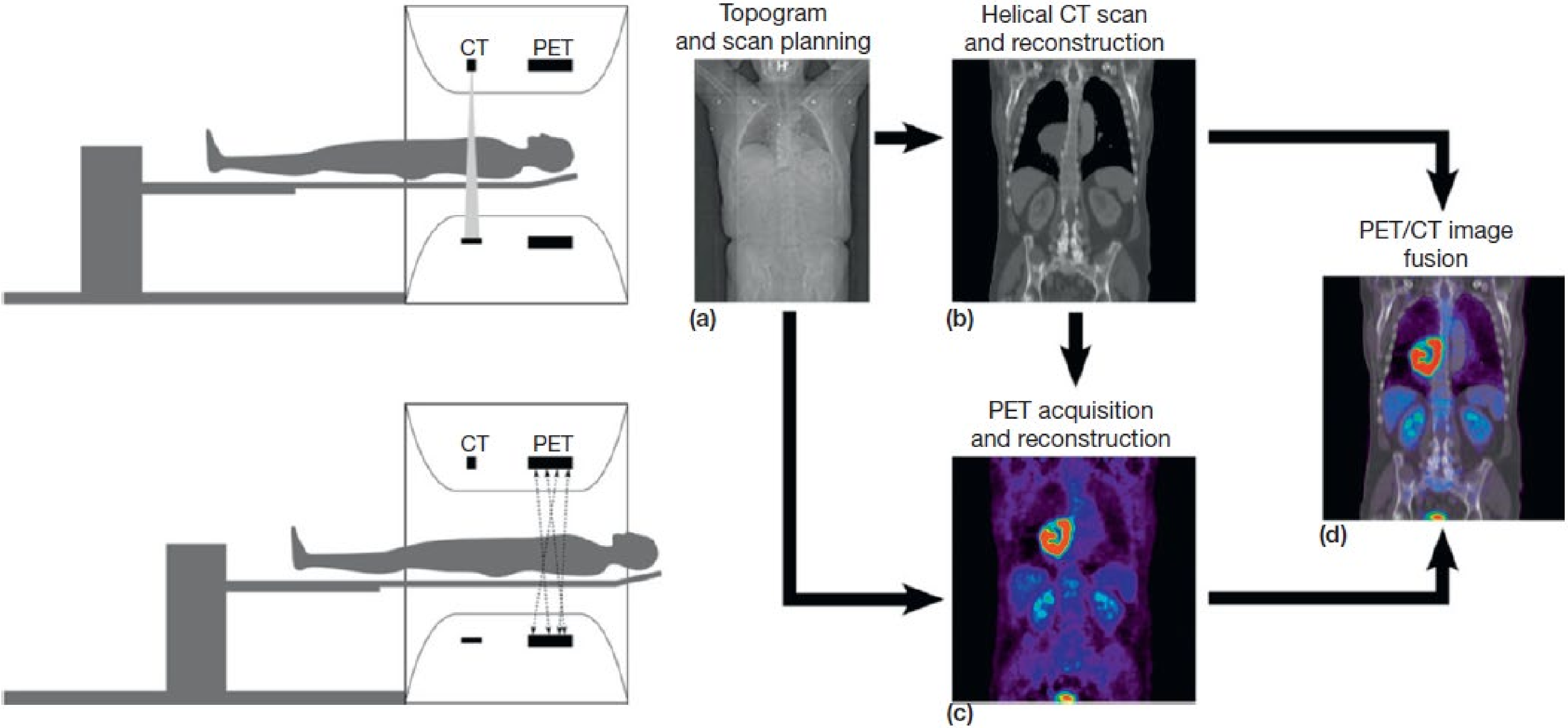
Uncorrected PET

CT

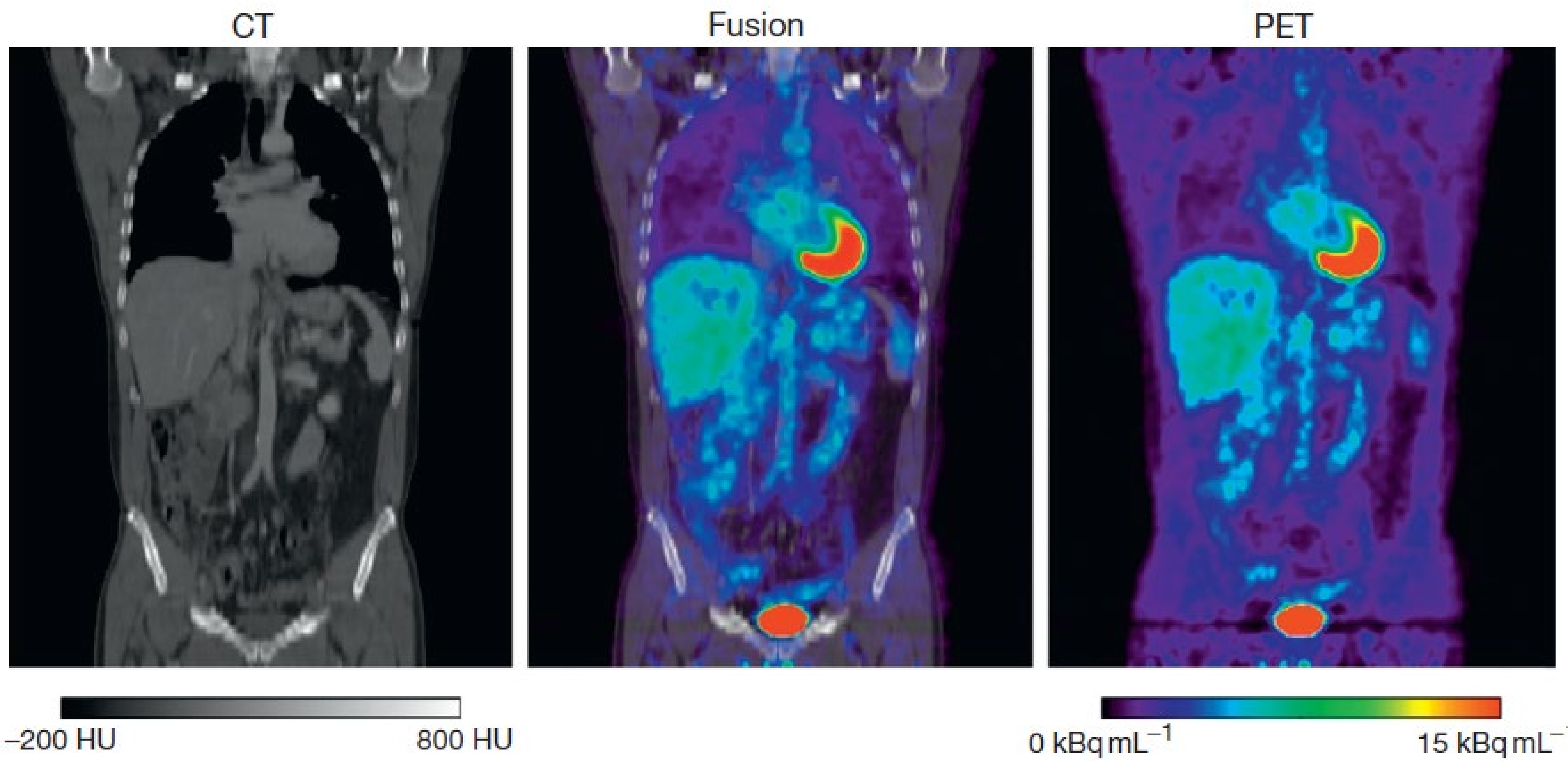


Corrected PET

PET/CT fusion imaging



PET/CT fusion imaging



Time-of-Flight (ToF) PET

- PET scanners based on crystals with a very short decay time and narrow coincidence window (e.g. LSO or LySO) are able to measure the difference in the arrival times of the two annihilation gamma ray photons with high precision
- The coincidence timing resolution, Δt, is measured as the FWHM of the histogram of ToF measurements from a point source (known as the timing spectrum)

Time-of-Flight (ToF) PET

- ToF information can be used to localize the emission point within a small region of the object